PRELIMINARY DESIGN OF MARS BASING

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PREFACE

This paper is an attempt to focus attention on the design and construction problems for a Martian base. An immediate, prefabricated, inflatable shelter is proposed for the first crew that lands on Mars which will serve for headquarters while additional base construction is performed. The use of indigenous materials for structures is proposed where possible to reduce transportation and construction costs. Prefabricated structures are advocated from imported materials, using steel, aluminum, wood, wood products, plastics, rubber fabrics or polyurethane plastics. Block construction could be used with either imported cements or with blocks and cements manufactured from Martian materials. The design and construction of basing facilities on Mars appears to be within the limits of present technologies, but it is emphasized that designs proposed herein will probably require considerable modification as more information about the environment and available materials on Mars is obtained.

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SUMMARY

The design and construction procedures on Mars will be governed by the environmental conditions which the structure must withstand, the constraints of this environment on the men building the base, and on the indigenous and imported materials available with which to build the base.

The low surface gravity on Mars (.38 of Earth's) will be a help for most operations by reducing the horsepower required to move vehicles and materials around. In traveling at any speeds, a vehicle will also be handicapped by the low gravity, since there will not be the usual restoring force as on Earth to return the wheels to the ground after hitting a bump. This suggests that a vehicle as wide as it is long may be the most feasible design.

The presence of an atmospheric pressure on Mars equal to that of an elevation of 55,000 feet above Earth will make the designs for sealing of compartments easier by reducing the pressure differential. This partial pressure will also make the required space suit quite simple, which will make the job of the construction worker fairly easy.

The ambient temperature range appears to be comfortable (80°F) around noon but will probably be quite cold at nights (-150°F).

It is improbable that seismic forces will have to be considered in design, so it is suggested that they be ignored.

It is considered a possibility that the topography of Mars may include slopes, faults, crevasses and low rolling hills since the definition of the lenses used to observe Mars cannot prove their existence one way or the other. However, selection of a good construction site should not be difficult since most of the surface appears to be fairly smooth.

The immediate expansion of living space by the forward party to land on Mars is proposed by attaching an inflatable structure sealed to the missile capsule with the air lock doors being in the other end of the capsule. Other initial construction proposed consists of additional inflatable structures and prefabricated structures transported from

Earth in a cargo missile. Secondary construction to complete the base is proposed to include masonry construction from indigenous materials or partly imported materials. Other inflatable and prefabricated structures might be used in the secondary construction stages also.

Other modes of construction suggested for its excellent insulation qualities would be cut and cover trench construction, tunneling for structures and modification of existing caves, cracks, or openings, if any.

Data on the exact conditions of terrain, soil type, temperature, pressure and physical characteristics of the surface and subsurface of the planet Mars are exceedingly sketchy and problematical. It is hoped and expected that Mars probes will clarify some of these doubts before a manned landing takes place.

I. INTRODUCTION

PURPOSE

The purpose of this paper is to discuss the design problems connected with the construction of basing facilities on the planet Mars and to propose some construction techniques and materials for use on such a project.

SCOPE

The effect of the very sketchy and speculative Martian environment, as generally accepted today, is considered in connection with the design and construction of basing facilities on Mars. Construction is classified as initial and secondary instead of temporary and permanent because the missile segments used for housing the initial landing personnel will most likely form a part of the permanent base complex. The use of indigenous materials which are expected to be available is discussed very briefly because this subject will be covered more thoroughly in Dr. Steinhoff's paper, "Use of Extraterrestrial Resources for Mars Basing."

Various materials and modes of construction are proposed using combinations of indigenous materials and imported materials or each separately. The use of any natural caves, crevices, or other openings that could be closed in for housing personnel and equipment is discussed. Making use of tunnels excavated by mining processes or cut and fill methods over arched rib structures is proposed. Inflatable rubber and fabric structures are also proposed as a rapid means of erecting a building in both initial and secondary construction phases.

BACKGROUND

Many authors have written on the exploration, colonization and landing on Mars. Dr. Steinhoff in his paper[(1)] proposed a landing on Mars with support by landings on Phobos. Chester R. Haig Jr., of McDonnell Aircraft Corporation proposed a colonization of Mars by a 100-man party, predicting that this could be accomplished by 1971.

R. F. Richardson wrote a book, "Exploring Mars,"[(2)] in 1954 which contains considerable discussion of possible means of exploring Mars. W. Von Braun wrote a book, "The Mars Project,"[(3)] in 1953 proposing that it would be possible to travel to Mars round trip from Earth with rocket propulsion and works out many of the details.

The construction of a base on Mars should be considerably easier than for one on the Moon because of the presence of some atmosphere and milder temperatures. However, life support facilities would be required on Mars in vehicles and buildings, though of less capacity than needed on the Moon.

II. ENVIRONMENTAL CONSIDERATIONS IN BASE DESIGN AND CONSTRUCTION ON MARS

ATMOSPHERE

The gases which are believed to be predominant in the Martian atmosphere, CO_2 and N_2, are non-oxidizing and will not present a chemical erosion factor.[4,5,6] However, it is possible that water vapor may be deposited in the form of dew or ice crystals. Though not so plentiful on Mars as on Earth, water thus formed on construction materials may be effective in chemical erosion or in frost wedging.

Probably the principal considerations in assessing the effect of the Mars atmosphere will be realized in wind forces effective on structures and in the atmospheric attenuation effects on radiation and meteoroid flux. Wind pressures on structures will be a design factor where exposure to surface conditions is a requirement, as in radio towers, beacons and operational equipment in landing areas. Atmospheric density on the Mars surface is roughly equal to 55,000 feet altitude on Earth. Thus, even high velocity winds will be far less dangerous in exerting "sail" effects on exposed buildings and equipment. It is expected that wind erosion will be effective in the removal of fine grained soils during any construction activity. However, it is not expected that such erosion will have the capability of transport in larger particles, i.e., surface sandstorms will not be a likelihood. Atmospheric attenuation of meteoroid infall, only slightly less effective than that on Earth, will offer a beneficial effect in reducing surface erosion and shelter penetration.

METEOROID FLUX

Meteoroid problems on Mars should be very insignificant, and the influx of larger meteoroids to the Mars surface should be approximately equal to that received on the surface of the Earth.[7,8] Thus, it is proposed that the following table of lunar meteoroid flux be accepted as being approximately correct for the total Martian surface:

Table 1

ESTIMATE OF TOTAL IMPACT FREQUENCY OF PARTICLES OF MASS INDICATED, IN IMPACTS PER YEAR

MASS	IMPACTS MIN.	IMPACTS MAX.
100 gram	165	495
1 kg	27	81
10 kg	4	13
100 kg	1	2

GRAVITY

Taking Earth gravity as a value of one, Mars has a calculated surface gravity of 0.38 or 12.7 feet sec^{-2}. This allows consideration of a reduced capacity and transportable weight in construction machinery used to accomplish any given task. Reduced gravity also is of benefit in design of structural foundations and in lateral stability. Lastly, a reduced gravity will tend to compensate for a lessened work capability for the Mars suited construction worker.

AMBIENT AND SURFACE TEMPERATURES

There is considerable disagreement on Mars temperature ranges (ambient) but unusual agreement on the fact that average daytime temperatures are acceptable to human life. At the equator a range of noontime 25°C maximum to dawn temperature of -50°C is proposed as a working range. Average daytime temperature should rest above the freezing point of water, 0°C. This average is derived from consideration of the known fact that water is vaporized and redeposited with seasonal variation. It is probable that with careful selection of an equatorial construction site, average low temperature can be minimized. This would tend to maximize working seasons when construction and scientific activities can proceed with the least difficulty due to wintering effects.

Land surface temperatures may differ considerably from those of

the atmosphere. It is probable that land surfaces exhibit considerably higher maximums than the 25°C ambient. Also subsoil temperatures would not fall to the designated ambient low. Thus, it is probable that subsurface structures or utility and fuel lines would have the benefit of a reasonably moderate and constant temperature, say at or above 32°F. In design of subsurface shelters this would mean manageable, low heat loss rates. For utility or fuel lines, it means favorable comparison of Mars equipment to that utilized on Earth.

SEISMIC ACTIVITY

Unfortunately, Mars photographs do not have sufficient resolution to illustrate the more detailed elements of geologic (planetologic) structure. However, it is believed that large masses of great altitude do not occur, nor are deep oceanic-type basins noted. Features characteristic of volcanic terrain are also lacking. Thus, seismic forces attributable to isostasy or volcanic action are probably infrequent or nonexistent. Initially, engineering design for construction can ignore seismic construction until such time as seismograph readings indicate the necessity for stronger safety considerations.

TOPOGRAPHY

As indicated previously, great differences in altitude are not apparently typical in the Martian terrain.[9,10,11,12] However, large scale terrain analysis for engineering purposes should not take this to mean that the surface will be entirely smooth or gentle. An assumption should be made that rough areas may exist, that local steep slopes may be encountered, or that crevasses or ancient faults may exist. The average picture, then, would suggest a low rolling desert terrain occasionally broken by steep slopes or broken areas not conducive to construction. However, it should not be difficult to select favorable construction areas.

RADIATION

On the Mars surface, radiation of concern during construction is

restricted to solar cosmic radiation which has been identified as transient, energetic, proton showers associated with flares from the sun. It is calculated that at Mars noon, solar visible radiation is about 43% of that received on Earth. This can be likened to a cloudy day on Earth, and should give sufficient light for most construction activities. It is very unlikely that the two small satellites of Mars reflect any usable light. Artificial lighting might be required for early morning and evening work and definitely for the interiors of shelters and night work outside.

Nuclear radiation can probably be neglected because the geology of the Martian crust does not predict any source of such radiation which would be greater than that experienced on Earth.

Galactic cosmic radiation in the vicinity of the Mars orbit should be similar to that measured near Earth. The atmosphere of Mars would attenuate such radiation on the surface such that the dosage rate would be tolerable by man for long periods of time. It is, therefore, estimated that special shielding would not be necessary for protection of workers on the surface of Mars from galactic cosmic radiation.

Solar cosmic radiation during solar flares might be of some danger to man on Mars. However, the usual solar activity would not be expected to cause a dosage rate in excess of the .03 rem per week allowed by the AEC. During intense solar flares, there will be sufficient warning that the crew could retire to shelters to wait out the storm.

SURFACE MATERIALS

Consideration here is restricted to the reddish-brown desert areas principally found in the equatorial and southern hemisphere regions. Polarization and brightness curves from these deserts are most closely approximated by pulverized limonite. This suggests that the desert areas are (1) vast plains of sand, which (2) have undergone extensive weathering during some prior age. In turn, this suggests the formation of various secondary minerals formed by oxidation and hydrolysis from primary igneous rocks. Admittedly, this is an arbitrary projection of poorly known data, but is one which presents a picture acceptable and familiar to the design engineer. Surface materials

will probably consist of a sandy soil with admixtures of rock fragments. Occasional zones of shallow or exposed rock may also occur. Conceivably, bearing pressures of 20 to 30 psi or better may be typical.

III. INITIAL CONSTRUCTION

MISSILE SEGMENTS AS INITIAL SHELTERS

The first manned flight will make a soft landing on Mars, keeping the missile intact and separating it in sections to be used as an initial shelter. This missile body would have the radio communications equipment, life support gear and navigational gear used on the flight in space, most of which could continue to serve the same purpose on the surface of Mars. In addition, it would have to have air-locks to permit the crew to leave and enter the capsule, stores of food and oxygen and tools for further exploration and construction efforts.

INFLATABLE STRUCTURES ATTACHED TO MISSILE SEGMENTS FOR IMMEDIATE EXPANSION

To provide immediate expansion of living quarters for the first crew that lands on Mars, it is proposed to inflate a rubber-fabric room which could be already attached to one end of the missile segment. The missile could thus be slightly overcrowded by several crew members in flight with this inflatable addition being completed within a few hours after landing, providing the necessary room from which to conduct exploration and perform other work. Air chamber and doors could already be located on the other end of the missile segment to provide ingress and egress, Fig. 1. The cells in the inflatable structure between the inner and outer fabric would be automatically filled with polyurethane foam by opening valves containing the proper amount of ingredients. Only temporary bracing would have to be used inside to shape the structure just prior to filling the air space with foam. This foam would provide the insulation necessary to protect the occupants against the cold weather in addition to maintaining the desired shape of the structure. The foam would also be used in the floor of this structure and would give adequate bearing capacity for personnel walking on it.

PREFABBED STRUCTURES

Perhaps the third type of structure built in the initial construction

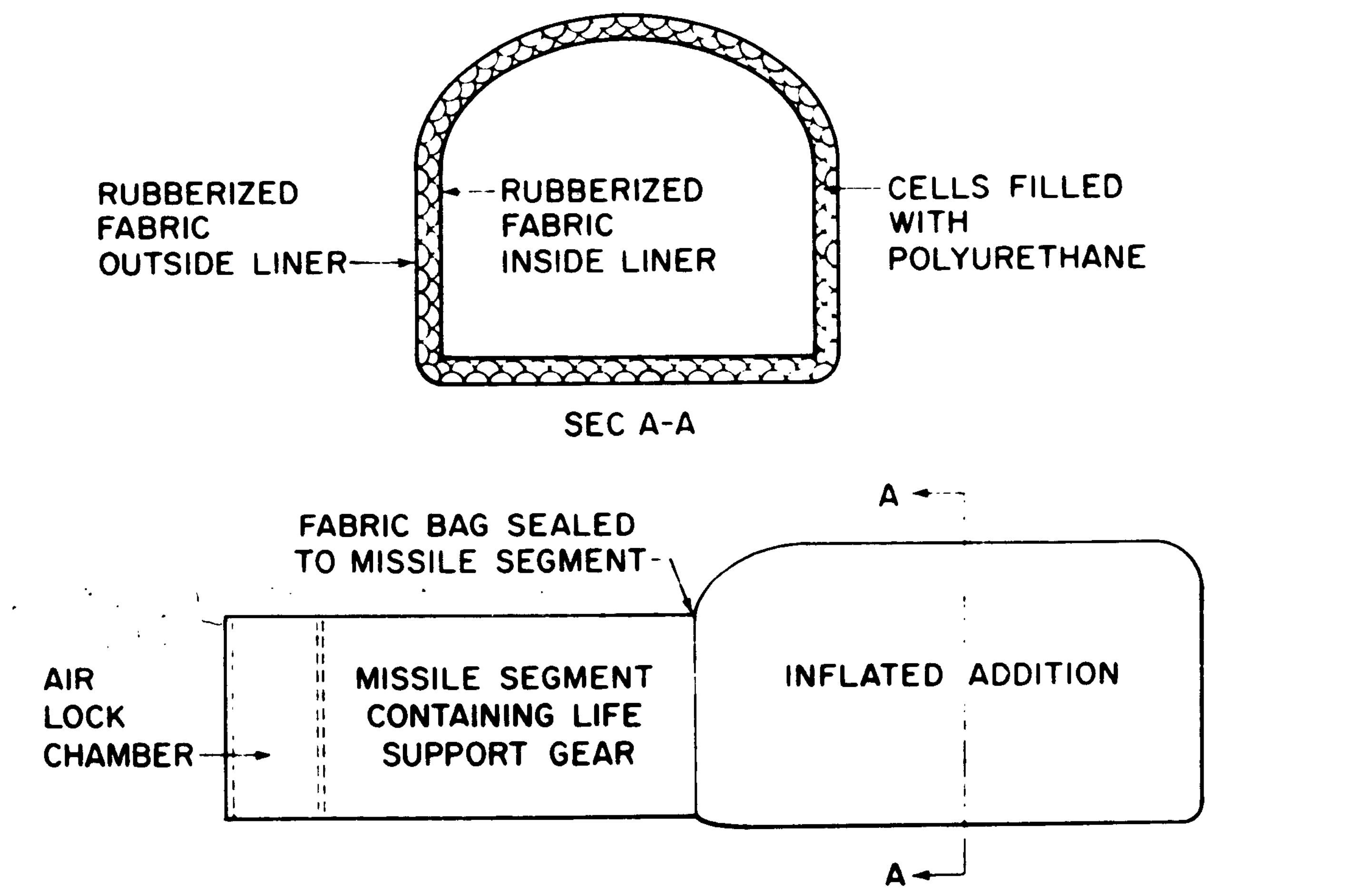

Fig. 1 — Initial expansion of living facilities for first crew landing on Mars

phases could be a prefabricated building made of aluminum, steel, wood, plastic, composition panel boards or any combination of these. Double wall construction could be used with a foamed-in-place polyurethane insulation and shielding for protection against the cold. Such a prefabbed structure could be hauled to Mars in the initial vehicle or transported in a separate cargo missile.

This type of light-weight building could be designed for the particular use required by the first landing personnel. Initial construction would be limited to provide only those buildings that were essential to sustain life until the second echelon of personnel arrived on the base with additional materials and requirements.

IV. SECONDARY CONSTRUCTION

USE OF INDIGENOUS MATERIALS

Consideration for use of local Martian construction materials should probably be restricted to the simplest of naturally occurring rock, rock products and water. As construction materials these would make rock blocks or bricks, aggregates and cementing materials in combination with water.

Rock for Masonry Construction

Assumptions on the availability of naturally occurring rock rubble are tenuous. Geologic processes may have resulted in local concentrations of talus or broken rock from meteoroid impact but these sources are entirely hypothetical. It would be better to assume the presence of relatively undisturbed bedrock which could be broken by explosives and shaped by laser gun techniques. This could conceivably supply building stone conveniently sized for masonry construction.

Cementing Materials

In this consideration a good deal of dependence is placed on the availability of secondary minerals formed by oxidation and hydrolysis of primary rock. The presence of limonite, as suggested in the section on Environmental Considerations, would be one source of such a cementing agent, in this case a ferruginous cement contained in the limonitic desert sand. Other secondary cementitous materials such as calcium carbonate or sulfur may occur. Addition of water to these naturally occurring sediments would result in a weak cementing material. The construction technique suggested here closely resembles the rock and adobe construction utilized in the prehistoric villages of the American Southwest and in Mexico. It represents a simple construction method with maximum utilization of local materials and small dependence on logistic support from earth.

Aggregates

From present information about Mars, it is impossible to predict whether sand and gravel, or building stones for masonry construction, exist in the natural state or not.

However, artificial aggregate could be obtained by the use of explosives on outcrops of naturally occurring rock. Usable size ranges would go from medium and coarse sand to medium-size gravel fragments. Crushing for production of optimum sizes, initially at least, would not be feasible.

Aggregate production may present production difficulties traceable to equipment requirements. Use of explosives to shatter the rock would be followed by sieving to separate and segregate the useable fraction. Equipment and equipment setup would be a logistics problem of no small magnitude if aggregates must be crushed and graded.

Water

Water supply may well be a simple problem as compared with currently suggested methods of lunar water production direct from rock. Water may be procured direct from water vapor in the atmosphere by temperature/pressure control methods. Secondly, the occurrence of permafrost zones beneath the soil surface may well be an immediate and easy source of water collection. Gravimetric survey methods could be an exploration method for location of such ice concentrations. Given adequate transportation methods, ice from the polar regions could be collected as water through frequent transportation to the construction site. Finally, if secondary hydrosilicate minerals such as serpentine occur in sufficient quantities, heating methods can produce moderate quantities of water (serpentine holds 12% water by weight). However, this method presents a problem of continuous production and processing of large quantities of rock.

As a construction material, water would be utilized with cement in masonry construction.

COMBINATION OF IMPORTED AND INDIGENOUS MATERIALS

Formed rock building stone will constitute the largest mass in any indigenous materials construction of shelters, scientific investigation structures or equipment protective cover. If indigenous cementing agents are not available or feasible in early construction, various transported agents or substances could be utilized without presenting a major logistics problem. These mortar substitutes could be plastic liner, plastic foaming agents (polyurethane, etc.) or common Portland

cement. The only requirement of the agent utilized would be that it offers a bonding strength to the native stone.

IMPORTED MATERIALS ONLY

Prefabbed Structures

The prefabbed structures considered in the secondary construction phases would be essentially of the same materials as those discussed under initial construction. However, the secondary structures might be larger, special purpose base support or scientific support buildings requiring more personnel and equipment to erect them than in the initial phase construction. The secondary buildings would also be those required for full base operations as opposed to those in the initial phase which were limited essentially to basic life support facilities only.

Cement and Cinder Block Structures

It is considered a possibility that some native cement materials will be found in Mars, such as sulphur or limonite.[2] If so, concrete blocks could be manufactured on the site and used for buildings, or the cement could be used for making masonry rock walls made of loose stones or quarried blocks of rock cut from the local building area by laser guns or other means.

For consideration also would be the transportation of cement to Mars via missile cargo flights and by using native Martian aggregates, construct poured concrete or concrete block structures. Concrete block, stone block and poured concrete construction is advocated on Mars as an excellent mode of building a base, either with imported or indigenous materials or a combination of both. Advantages would be excellent stability, natural shielding, insulation against the cold temperatures, and flexibility of building plans to match needs.

Inflatable Rubber and Fabric Structures

Again, the same type of inflatable structures was considered under initial phases of base construction, but the buildings in the secondary phases would be larger, special purpose units required to carry out the missions of the expedition. These might consist of garages, work shops, celestial observatory facilities, communication buildings, and expanded

messing and berthing facilities for the balance of the crew.

The structural bracing placed inside these inflatable structures could be a combination of wall and ceiling panels and structural members. This would give usable wall space for attaching shelves and furniture, and probably provide adequate shielding protection as well as the very necessary insulation.

Shielding requirements are not being made a part of this study, since others will treat this subject in detail. It is sufficient to say that the shielding required on Mars is not being predicted as significant for protection against galactic cosmic rays and solar flares.

NATURAL FACILITIES

There may be natural caves, crevices or cracks on Mars which could be sealed off by construction of bulkheads and roofs for use as shelters. If found, this offers an economical method of obtaining spaces that would be well shielded against radiation hazards and well insulated against the low temperatures. It is quite likely that an underground shelter will have to be dug, if natural cavities are not found, for use as an emergency shelter during the most violent solar flare periods. Thus, the normal structures would not need the shielding for protection against major solar flares, if all personnel retreated to the storm shelter for the duration of the flares.

BURIED STRUCTURES

Tunnels

Tunnel construction may provide an ideal way to obtain safe structures. The tunnels could be mined, blasted, or bored by standard procedures. Laser guns now being developed for cutting rock might be employed for cutting such tunnels. Advantages of using tunnels would be the natural shielding provided against radiation, good insulation against cold temperatures, and protection against wind damage. The use of the laser would require an operator in a space suit and unlike on the Moon, such space suits would be relatively light and simple. A man should be able to perform quite a lot of physical labor out in the open on Mars.

Cut and Cover Construction

Similar to the construction by the Army Corps of Engineers of the ice cap experimental station, Camp Century, buildings could be erected in cuts and covered. This may be simpler to construct than tunnels and would offer the same advantages. Sealing the interiors of such cut and cover structures could be done by use of plastics or by the structure materials, depending upon the type used.

Interior liners could be semi-circular light-weight steel sections similar to the corrugated iron huts used in World War II for ammunition storage. Masonry or block walls would also be usable. The edges of the cut trench could also form the side walls of the structure with the roof as the only portion to be constructed and sealed to the trench walls.

Appendix A

GENERALLY ACCEPTED MARS NUMERICAL DATA

1. ATMOSPHERE
   - (a) Composition approximately estimated at 2% CO_2, 98% N_2 with a trace of A
   - (b) Pressure 85 millibars
2. TEMPERATURE
   - (a) Maximum 80°F
   - (b) Minimum -150°F
3. GRAVITY
   - (a) .39 of Earth's or 12.7 ft sec^{-2}
4. LENGTH OF MARTIAN DAY
   - (a) 24 hr 37 min 22.6 sec
5. LOCATION OF MARS IN SPACE
   - (a) Average distance from Sun 227.7×10^6 km
   - (b) Minimum distance from Earth 56.3×10^6 km
6. DIMENSIONS
   - (a) Equatorial Diameter - 4100 mi / 6800 km
7. PHYSICAL CONSTANTS
   - (a) Density (water = 1) 3.8 - 4.0 ±
   - (b) Volume (Earth = 1) 0.153
   - (c) Mass (Earth = 1) 0.108
   - (d) Escape Velocity 5.091 km/sec
   - (e) Mean Orbital Velocity 24.11 km/sec
8. INCLINATION OF AXIS OF ROTATION
   - (a) 24.8°
9. SIDEREAL PERIOD
   - (a) 687.979 days
10. SOLAR RADIATION INTENSITY (EARTH = 1)

(a) 0.4315

11. **ALBEDO**

(a) 0.15

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